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The AFSC Cost Methods Improvement Program (CMIP) Road Map

by

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INTRODUCTION

The development of cost estimating tools virtually came to a standstill after the surge of RAND and other studies ended in the early 1970s. The cost estimating "tool box" used to estimate today's systems is based on methodologies, problems, and technologies that are pushing 20 years of age. Some of the tools are not adequate to estimate today's systems with their new technology. The Air Force Systems Command (AFSC) Cost and Management Analysis Directorate has developed a comprehensive long range program to restock the estimating "tool box" with new estimating capabilities.

The program is called the Cost Methods Improvement Program (CMIP) and was formed with the development of the AFSC Cost Analysis Improvement Group (CAIG) in 1981. The CAIG is chaired by the Director of Cost and Management Analysis at HQ AFSC and has as members each of the AFSC Product Division's Cost Analysis Directors. The CAIG prioritizes and approves funding for research projects which benefit more than one Product Division. The CMIP is managed at HQ AFSC with most of the individual projects passed on to the Product Divisions.

The AFSC CAIG was formed to mirror a similar group formed at HQ Air Force. The purpose of the CAIG, is as its name implies, to improve the cost analysis function within AFSC. At the onset the CAIG started a research program aimed at cost estimating. The reason a concerted effort was made in this area was that little cost estimating research was being accomplished at that time. The first year of funding, 1982, was a minimal effort of only $200,000. Since that time the funding and number of projects has increased. Funding is now supported in the Air Force Program Objective Memorandum through Fiscal Year 1991 at a total of $8M.

The first few years of the CMIP saw various projects started and completed. These included software data base generation, host vehicle/subsystem integration costs and Very High Speed Integrated Circuit (VHSIC) cost relationships. Three projects were of a long term nature and are; the Cost Analysis Handbook, Production Rate Model and Microelectronic Road Map. These projects were conceived to be dynamic projects which would change as technology, cost relationships, and other factors changed.

One of the biggest and highly supported projects was the development of the Cost Analysis Handbook. This handbook is designed to be used like an engineers handbook. Every cost analyst in the Air Force will get one for their desk. The handbook is primarily for the new cost analyst and is to provide them with tips, shortcuts, and rules of thumb that an analyst would learn after years of experience. The handbook is to help speed up the learning process, as well as provide a good detailed reference for the experienced analyst.

PROJECT SELECTION

Research projects are submitted by the Product Divisions to HQ AFSC for funding consideration. These projects are then discussed among the members of the CAIG to determine final prioritization and funding. The projects under consideration represent the Product Division's needs for the upcoming year. These needs show where new estimating "tools" are required.

HQ AFSC had no indication, other than the list of projects, of what the long term needs of the product divisions were. With the development of the CMIP Road Map, a means for assessing the long term needs was realized. Because the Road Map was developed with the help of all the product divisions, the HQ AFSC CAIG now has more than a list of projects to help them prioritize the funding and planning of projects.

The Road Map helps the prioritization process by dividing areas of need into: (1) New Research Areas, (2) Technology Areas, (3) Other Research Areas, and (4) Survey Areas. These four categories emerged during the Road Map study. A cost estimating framework was first developed in which the changing nature of the cost estimating problem could be classified with respect to advancing technology and to the development life cycle. Research Areas requiring improved cost estimating methods were identified within this framework. Interviews were then conducted with key Air Force Product Division and Tecolote cost estimators. Modifications to the Research Area list were made and specific topics in Technology Areas, Other Research Areas, and Survey Areas were also identified.

The research areas include:

- Quantify State-of-the-Art
- Extrapolation Estimators for Evolutionary Advance
- Technology Breakthrough Evaluation Prior to DSARC II
- DSARC I Cost Estimating Methods
- Technology Impacts on Acquisition Costs
- Technology Impact on State-of-the-Art System Characteristics
- Normal FSD Schedule/Cost Estimate
- FSD Cost Consequence of Technology (Schedule) Compression
- Methods to Estimate Advance Development Costs

These research areas represent longstanding problems that cause great heartburn. Getting to the bottom of some of them may be extremely difficult, if not impossible, as many are institutional in nature. Institutional problems represent problems with the bureaucracy, "the way things are done." For example, trying to lock in a system definition prior to DSARC I is impossible and will always cause system cost estimating problems. Integration cost estimates are also required very early in a subsystem's life to determine if it should be installed on certain platforms. At the time these estimates are required, the subsystem is far from a final definition, yet "yes," "no" decisions are expected. These research areas must be studied to see if there is a better way to estimate costs even with the uncertainty.

The Technology Areas were a fallout of the interview process mentioned above. Technology identification was not the intent of the Road Map. However, it was apparent in the discussions that the following technologies were of high interest:

- Very High Speed Integrated Circuits (VHSIC)
- Computer Aided Design (CAD)
- Computer Aided Manufacturing (CAM)
- Gallium Arsenide (GaAs)
- Composite Materials

These technologies appear to be affecting our estimating capabilities soonest. These technologies will impact our Cost Estimating Relationships (CERs) and may change the attributes (physical or performance) that are cost drivers in the CERs.

The other Research Areas represent areas which are more specific than the Research Areas identified earlier. These areas include:

- Software Size Estimating
- Historical Schedule Inefficiencies
- Estimate Quality
- Non-Primary Mission Equipment Cost
- Host Vehicle/Subsystem Integration Costs
- Commonality Problems
- Software Cost Estimating
- Evaluation of Estimates Made by Price

In addition, some areas identified have had significant research previously completed and a survey of the area, disseminating the ideas is the next logical step. THese have been identified as Survey Areas and include:

- Correcting for Biased Cost Drivers
- Imbedded Cost Estimating Practices
- Competition Impacts
- Multiyear and Warranties
- Production Rate Effects
- Contractor/Subcontractor Integration Costs

Although some of the areas identified above include past CMIP projects, the Road Map brings together the views of all product divisions on a particular project. The benefit is that when one product division may feel a certain project is "hot" and benefit other product divisions, the Road Map brings the Command's needs into perspective and that project can be evaluated from a top level viewpoint. It may turn out that the other product divisions may not need the project. By having existing projects in the Road Map, a long term need is established for these project areas and consequently continued funding and high prioritization are needed.

EXCERPTS FROM THE ROAD MAP

Excerpts from the Research Road Map study follow. They have been extracted from "Air Force Systems Command Cost Research Road Map," by C. A. Graver, CR-0076, Tecolote Research, Inc., July 1985. This document will be available from AFSC/ACC on or about 2 October 1985.

Highlighted in this section will be all of Section 1 and 2 and parts of Sections 4 through 8. The excerpts will then be followed by a brief summary.

1
INTRODUCTION

STUDY OBJECTIVE

Headquarters, Air Force Systems Command (AFSC)/ACC is charged with the responsibility of providing timely and accurate cost estimates for future USAF acquisitions. Cost estimating techniques used to accomplish this mission have been developed over the last twenty-five years. These techniques are based on solving estimating problems associated with previous and current technologies. As such they are not always appropriate for estimating the cost of acquisitions that incorporate new technology or use new contracting methods.

Over the past ten years, cost research has largely been focused on applying these previous cost estimating methods and techniques to current estimating problems. Little attention has been given to the examination of the entire estimating process. Are there fundamental estimating problems which have not been addressed? Is there a need for entirely different estimating technologies which require new estimating approaches?

The purpose of this study is to step back and take this overview of the cost estimating problem and then to define new cost research directions. Specific research tasks are not to be delineated. Also, the study's focus is on estimating capabilities and techniques as opposed to institutional problems such as staff training or the automation of estimates.

The secondary objective is to identify research problems of common interest, across the Product Divisions. These topics are candidates for AFSC funding, whether they are new research areas or extensions of existing research or techniques.

Specific cost estimating problems without broad interest are not candidates for the cost research roadmap unless they can be used as examples to develop and demonstrate a new technique.

Also excluded from the study are the following:

Operations and Support (O&S) cost
Institutional and procedural changes
Automation intended to increase estimating efficiency
Technical recruiting
Black world problems

STUDY APPROACH

Tecolote Research, Inc. (Tecolote) was asked to conduct this study. Initially three steps were envisioned, as paraphrased from the statement of work.*

1. Compile a List of Cost Research Areas
   Tecolote will compile a list of cost research areas, primarily through brainstorming sessions with senior Product Division and Tecolote personnel. Formal study plans will be reviewed as a background to the interviews. However, the primary source of information will be the interview process in that the primary focus of the study is on study areas not being addressed and on requirements for new techniques. Current study plans will be a good starting point for the discussion.

   Tecolote will contact as many Product Divisions as feasible. Interviews will also be made with non-Air Force personnel as resources permit.

2. Organize Ideas into Research Areas
   Items surfaced during the interview process will be organized into research areas. These research areas may have common technical thrust, data requirement, generic problem, or other unifying dimension.

3. Establish Priorities
   Priorities will then be established within and across the research areas. The criteria will consist of timing (when will it be needed?), importance (how significant is the cost?) and doability (promising techniques, data sets?). The result will then be an aggregated "game plan" for cost research.

STUDY CONDUCT

In reality, after the first interviews, it became apparent that a framework was required in which the various dimensions of the cost estimating problem (procurement phase, technology requirements, etc.) could be synthesized and holes could be identified where existing cost estimating techniques were insufficient. Such a framework was developed, based on the author's experience and remarks from the initial interviews. New research areas, where new techniques need to be developed, were defined from this framework.

*Extracted from study overview sent to the Product Divisions, prior to interviews.

Subsequent interviews were used to expand and more precisely define this framework. In addition, these interviews brought up additional specific estimating problems.

These ideas were cross-referenced into research areas which fell into three broad groups:

1. new research areas (identified from the framework)
2. new technologies
3. other research areas.

An evaluation was made of each identified research area. This included the following:

Definition - a short, precise definition of the area.

Significance - a qualitative statement about the significance of the research area.

Product Division interest (Applicability) - a simple check for Product Division expressing interest (from the interviews) or having possible interest due to the potential applications.

Discussion - a free flowing discussion of the research area.

Related Areas - Identification of how this area relates to other research areas.

Doability - an assessment of the difficulty to achieve significant success in the research effort.

Priority - Significance and doability are combined into a rating of extreme, high, medium, or low.

Recommendation - a recommendation as to whether or when the research topic should be pursued, based on priority.

Research Steps - an outline of research steps for research areas recommended with extreme or high priority.

During the research area presentations, remarks from interviewees are often cited. The Product Division will also be identified so that commonality of interest may be assessed. Product Division personnel are generally from the ACCs. In the case of non-government personnel, the Product Division most closely supported by the individual will be cited. This, of course, does not imply any direct employment affiliation. Furthermore, Product Division sanction is not given to any of the remarks from government or non-governmental personnel.

REPORT ORGANIZATION

The remainder of this report is contained in seven sections. The Framework is contained in Section 2. New research areas identified in Section 2 are described in Section 3, following the format discussed above. Interaction between the New Research Areas is shown in Section 4. Technology topics are contained in Section 5. They are candidates for development of cost research methods defined in section 3.

Other research areas are contained in Section 6. Significant work has already been done in many of the areas. In some cases, it appears that a critical survey of techniques would serve the AFSC cost community better than another research effort. In such cases, the topic is discussed in Section 7, Survey Topics.

Final recommendations are then summarized in Section 8. This includes a priority sorting across the research areas.

Cross references between topics is made throughout the report. A shorthand notation was adopted to facilitate the cross referencing. These are listed below along with the topics:

1. New Research Areas (described in Section 3) are referenced with Roman numerals (I-IX).

- I. Quantify State-of-the-Art (SOA)
- II. Extrapolation Estimators for Evolutionary Advance
- III. Technology Breakthrough Evaluation Prior to DSARC II (Uses V and VI)
- IV. DSARC I Cost Estimating Method(s)
- V. Technology Impact on Acquisition Cost
- VI. Technology Impact on SOA System Characteristics
- VII. Normal FSD Schedule/Cost Estimate (Schedule Normalization)
- VIII. FSD Cost Consequences of Technology (Schedule) Compression
- IX. Methods to Estimate Advanced Development Costs

2. Technology Areas (Section 5) are referenced by a number following the letter T (T1-T5).

- T1. Very High-Speed Integrated Circuits (VHSIC)
- T2. Computer-Aided Design (CAD)
- T3. Computer-Aided Manufacturing (CAM)
- T4. Gallium Arsenide (CaAs)
- T5. Composite Materials

3. Other Research Areas (Section 6) are referenced by number following the letter O (01-08).

- 01. Software Size Estimating
- 02. Historical Schedule Inefficiencies
- 03. Estimate Quality
- 04. Non-Primary Mission Equipment Costs
- 05. Host Vehicle/Subsystem Integration Costs
- 06. Commonality Problems
- 07. Software Cost Estimating
- 08. Evaluation of Estimates Made by PRICE

4. Survey Areas (Section 7) are referenced by number following the letter S (S1-S6).

S1. Correcting for Biased Cost Drivers
S2. Imbedded Cost Estimating Practices
S3. Competition Impacts
S4. Other Contracting Method Problems
S5. Production Rate Effects
S6. Contractor Integration Cost Estimation

2
FRAMEWORK

The biggest problem in defining future research directions that have not been sufficiently addressed by the cost community is to impose some structure on the overall cost analysis problem. Within this structure areas can be identified where the cost analysis community has done a good job and others where improvement is needed. The following four charts show the structure. They show the cost problem as it relates to system requirements growth, life-cycle phase, technology breakthroughs, and schedule/cost tradeoffs in full scale development (FSD). Roman numerals in circles on these charts refer to research areas which appear not to have been (sufficiently) addressed by the cost community. These research areas are discussed further in section 3.

CHART 1: TECHNOLOGY AND COST FROM A SYSTEM ORIENTATION

When making a cost estimate of a proposed system, the analyst has to make sure that the cost estimating tools have been developed for the estimating problem. These estimating problems will differ with the degree of technology advance required in the system as a whole or in specific subsystems.

Technology advance can be classified into three different levels. First, State-of-the-Art (SOA) requirements apply to subsystems which have been built or are so close to subsystems which have been previously built that no advance in technology is required. Here, our traditional cost estimating tools are extremely good. Analogies will usually exist, and CERs built for interpolation, such as those produced by least-squares regression, are often available.

The main estimating concerns are: (1) various management questions that affect the cost or, (2) specific cost components where existing estimating techniques can be improved. Management questions include all the new contractual clauses affecting production costs such as warranties, the impacts of competition, etc. Support equipment is an example of a cost component that could use CER improvement. These important considerations need study, but they basically represent fine-tuning an already good estimate.

The second technology level, called evolution, refers to extensions of existing technology which will normally happen given enough time. They do not depend on any great technical breakthrough. Traditional estimating techniques have not explicitly been built for this type of estimating problem. They have not made use of the available data to test the power of the estimating techniques for such extrapolations.

There have been some attempts to account for technology growth by a time factor, but these really don't score the estimating procedure on how well it extrapolates. What is needed are estimating techniques that have demonstrated successful extrapolation in the required direction of technology growth. This will be new research area II. For the present, techniques which have demonstrated extrapolation capabilities will be called extrapolation estimators.

CHART 1

TECHNOLOGY AND COST:
SYSTEM ORIENTATION

TECHNOLOGY REQUIREMENTS	COST METHODS DESCRIPTION	AVAILABILITY
SOA	INTERPOLATION CERs ANALOGIES	GOOD; MANAGEMENT QUESTIONS EXIST
EVOLUTION	ROBUST ESTIMATORS	NEGLIGIBLE II
BREAKTHROUGH	SPECIAL STUDIES	DONE TOO LATE III

I NEED METHOD FOR TECHNOLOGY CLASSIFICATION

NOTE: ROMAN NUMERALS IN CIRCLES (E.G., V) REFER TO THE NEW RESEARCH AREAS DESCRIBED IN SECTION 3.

Little formal work has been done in this area, although procedures are available for testing estimating techniques for extrapolation. Some existing estimating techniques (CERs) will hold up well when tested for extrapolation others will not.

The third level of technology growth is one that requires a technical breakthrough. What is desperately needed is an acceptable technique for examining the system physical/performance characteristics to quickly identify when a breakthrough is required (this constitutes research area I as shown in chart 1). Such a technique will also be able to examine system (subsystem) requirements and classify technology growth into any of the three categories discussed above. (Candidates for this technique exist; they need to be examined and one selected.)

When a breakthrough requirement is identified, the role of the cost analyst is first to find out what breakthrough the Program Office (PO) is depending on. If the answer is none, then a big red flag should be raised. The system is in trouble and the cost estimate should reflect the risk. When a specific breakthrough is identified by the PO, special cost studies are required. These special studies will constitute research area III. In general, these studies are started far too late (or not at all). The time to begin is in the laboratory or during concept validation. Refer to chart 3.

CHART 2: TIMING OF ESTIMATES WITHIN THE ACQUISITION LIFE CYCLE

DOD level reviews are held at key milestones in the system development. These reviews are made by the Defense System Acquisition Review Committeee (DSARC). As originally envisioned, three reviews were to be held which had to be successfully completed prior to the system's passing into the next phase of the acquisition life cycle, as shown below:

Phases	Phases
Concept Formulation	
	DSARC I
Concept Validation	
	DSARC II
Full Scale Development	
	DSARC III
Production	

During Concept Formulation, alternative combinations of technology are examined to find a single combination that will the threat. Approximate levels of system performance are determined and the concept presented at DSARC I. The work normally consists of paper studies administered by future sysystems analysis groups (XR) within the product division.

During Concept Validation, the concept is tested to show that high-risk technologies can be made to work together. Engineering prototypes sufficient to validate the concept are developed and tested. Specific physical characteristics of the new technologies are selected. Work is often performed in government labs or by outside contractors, administered by a fledgling Program Office (PO). Resolution of all technical risk areas is presented at DSARC II. Tasks performed between DSARC I and II are often referred to as Advanced Development.

During Full Scale Development (FSD), or Full Scale Engineering Development (FSED), prototypes of the entire system are developed and tested to demonstrate system performance and producibility. Work is most often performed by a defense hardware (software) contractor under the guidance of the System PO. Results are presented at DSARC III, where a production decision is made.

This ideal description of the process will be used in discussing the research areas presented in this study. It is recognized that this ideal is not always followed.*

Chart 2 addresses the changing nature of the cost problem as the system moves through the DSARC review process. It is connected with the first chart in that cost problems prior to and including DSARC I and II tend to address evolutionary or breakthrough advances in technology, at least for some subsystems.

Prior to DSARC I, the system description is vague, there are many technical problems, and hence the subsystem performance levels necessary to meet DOD requirements are only vaguely defined. Yet, estimates are required for FSD and production, and these numbers will be attached to the system concept and be used in system evaluation by Congress. How are reasonable (unbiased) estimates made with such uncertainties? Traditional techniques do not address this problem. This will constitute research area IV.

A related problem at DSARC I is estimating the cost of concept validation, the advanced development phase. Techniques and data for these costs are almost nonexistent. This will constitute research area IX.

Between DSARC I and II, cost/performance tradeoff curves based on the new technologies need to be developed so that specific physical and performance characteristics can be selected. Less detailed curves should be developed prior to DSARC I for technology selection. Development of these curves is research area III.

*The hand-off of responsibility from XR to the PO does not always happen at DSARC I. Furthermore, more than one set of technologies may be carried into Concept Validation, especially in high-risk programs with tight deadlines. Similarly, not all technical problems have been resolved prior to FSED. Surthermore, a low-rate initial production (LRIP) may be started, after an initial DSARC III review and prior to the final DSARC III review.

CHART 2

TIMING OF ESTIMATES

TIMING	SYSTEM DEFINITION	TECHNOLOGY PROBLEMS	CURRENT ESTIMATING PROBLEMS AD* FSD PROD
DSARC I	VAGUE	MANY	HOW DO WE ESTIMATE? IX IV NUMBER MAY HAUNT US.
TRANS-ITION			COST PERFORMANCE TRADEOFF CURVES III
DSARC II	GENERALLY DEFINED	RESOLVED CONCEPTS RISK AREAS REMAIN	COST/ SCHEDULE VII PROD TECH V
DSARC III	DETAILED	RESOLVED	MANAGEMENT QUESTIONS

*AD IS ADVANCED DEVELOPMENT

NOTE: ROMAN NUMERALS IN CIRCLES (E.G., V) REFER TO THE NEW RESEARCH AREAS DESCRIBED IN SECTION 3.

By DSARC II the technology problems have presumably been resolved and the system defined. The cost/performance tradeoff curves should form the basis of the estimate in the new technology areas. Hopefully they will also have been used in the system definition process. Estimating problems shift to estimating cost/schedule tradeoffs in FSD (research area VII) and cost impacts of new production technology (cost research area V).

By DSARC III the system definition is very detailed and the technology problems, other than those of high-rate production, should have been resolved. Prototype costs are known and production estimates using existing techniques should have high quality. Only the contractual form and management questions should remain a cost estimating problem.

CHART 3: TECHNOLOGY BREAKTHROUGH COST PROBLEMS

What then are the cost problems when the system characteristics require a technology breakthrough? (Identification of the breakthrough is assumed, or the system is in trouble.) Breakthrough cost impacts must be estimated, research area V.

The first estimating problem is "How will production costs change?" If the breakthrough is or requires a new production technique, industrial engineering (IE) studies are required to see how the new technique would be applied to previously built systems and to thereby estimate how the production costs would change. However, this will only establish a single point on a cost/performance curve, so extrapolation from these studies is an unresolved cost problem.

The next problem is "How will FSD costs change?" The big unknowns are design and testing factors. Fabrication costs should relate to production estimates.

Another problem is "How will the SOA change with the new technology?" The new technology may make previously far-out system advances into SOA applications. The Technology classification tool called for in Chart 1 may be the technique to describe the change in the SOA. This will be research area VI.

Finally, "How will the technology be applied?" This is related to the point above. DOD rarely uses a breakthrough only to reduce costs. More generally, DOD buys more capability, and this may even be an evolution from the new SOA called for in the previous paragraph. This consideration is part of research area IV.

CHART 3

IMPACT OF TECHNOLOGY BREAKTHROUGH

NO CONSISTENT METHODOLOGY

EFFECTS ON DEVELOPMENT OR MANUFACTURING PROCESSES (V)

IDENTIFY IMPACT ON
- PRODUCTION (COST AND RATE)
- DESIGN (COST AND TIME)
- TESTING (COST AND TIME)

EFFECTS ON SYSTEM CHARACTERISTICS

MEASURE NEW SYSTEM STATE-OF-THE-ART CHARACTERISTICS (MODIFY (I)) (VI)

DEFINE THE LIKELY SYSTEMS CHARACTERISTICS THAT WILL BE BUILT USING THE NEW TECHNOLOGY (IV)

NOTE: ROMAN NUMERALS IN CIRCLES (E.G., (V)) REFER TO THE NEW RESEARCH AREAS DESCRIBED IN SECTION 3.

CHART 4: SCHEDULE/COST/TECHNOLOGY INTEGRATION

A big problem in FSD, which is only accentuated when a technology breakthrough is required, is the establishment of an FSD program with cost, schedule, and technology advance requirements all balanced. The central question is: how does one make a "normal" FSD schedule, assuming that FSD cost is to be minimized and that no accelerated technology growth requirements are present? This question constitutes research area VII.

To accomplish this, schedule estimating relationships for normal FSD programs will have to be developed from a (nonexistent) schedule data base which has been normalized for elongated programs (stretch-outs due to budget cuts) or accelerated programs (affecting schedule only or schedule and technology). (Note that these two accelerated-porgram effects are known as schedule compression and technology-schedule compression, respectively.) Such schedule normalization techniques have never been developed. Yet, trying to develop estimating relationships without such normalized schedule data is equivalent to building CERs with then-year cost data.

Once normal schedule estimating techniques are available, an FSD cost estimate can be allocated to the schedule. Techniques exist but have not been formalized, standardized, or criticized.

Next, the cost impacts of schedule changes due to acceleration or stretch-out can be estimated. Stochastic networks will do the job. However, no technique exists to estimate the cost impacts of technology compression. The only way to alert the reviewer to the problem is through increased risk. This will be research area VIII.

CHART 4

SCHEDULE/COST/TECHNOLOGY
INTEGRATION

ESTABLISH A NORMAL FSD ESTIMATE (VII)

BUILD SCHEDULE USING SCHEDULE ESTIMATING RELATIONSHIPS NORMALIZED FOR:

- MINIMUM FSD COST
  NO TIGHT DEADLINES (SCHEDULE COMPRESSION)
  NO BUDGET CONSTRAINTS

- NOMINAL TECHNOLOGY GROWTH (TECHNOLOGY LEVEL AVAILABLE WITHIN THE SCHEDULE)

SCHEDULE/COST ADJUSTMENTS

REASON	TECHNIQUE	AVAILABILITY
COST OF COMPRESSED SCHEDULE-SOA TECHNOLOGY.	STOCHASTIC NETWORK	AVAILABLE
COST OF EXPANDED SCHEDULE DUE TO BUDGET CUTS.	STOCHASTIC NETWORK	AVAILABLE
COST OF COMPRESSED SCHEDULE WITH EARLY TECHNOLOGY REQUIREMENT.	RISK BUT NO COST	(VIII) NOT AVAILABLE

NOTE: ROMAN NUMERALS IN CIRCLES (E.G., (V)) REFER TO THE NEW RESEARCH AREAS DESCRIBED IN SECTION 3.

3

NEW RESEARCH AREAS

From the framework analysis, nine new research areas were defined. These are shown on Chart 5. The Roman numerals associated with each area have been referenced on the four charts in the previous section.

Research Area VII will serve as an example of the material presented for each topic.

CHART 5

NEW RESEARCH AREAS

<u>ITEM</u>

I. Quantify State-of-the-Art

II. Extrapolation Estimators for Evolutionary Advance

III. Technology Breakthrough Evaluation Prior to DSARC II (Uses V and VI)

IV. DSARC I Cost Estimating Method(s)

V. Technology Impact on Acquisition Cost

VI. Technology Impact on SOA System Characteristics

VII. Normal FSD Schedule/Cost Estimate (Schedule Normalization)

VIII. FSD Cost Consequences of Technology (Schedule) Compression

IX. Methods to Estimate Advanced Development Costs

RESEARCH AREA VII

"NORMAL"FSD SCHEDULE/COST ESTIMATE

DESCRIPTION: Develop schedule normalization technique(s) which will adjust data for Schedule Compression (tight IOC) and Schedule Expansion (funding cut). Develop "normal" schedule estimating relationships.

SIGNIFICANCE: The impact of schedule on cost is significant. Schedule compressions and expansions both increase cost. Network techniques for estimating these cost impacts exist once a "normal" schedule has been laid out. However, no technique exists for laying out a "normal" schedule, i.e., one that is balanced in schedule and technical risk while minimizing cost.

PRODUCT DIVISION INTEREST (APPLICABILITY):

AD	ASD	BMO	ESD	SD
X	X	X	X	X

DISCUSSION: Schedule estimation is still a black art. Initial schedules are laid out by the contractor and then adjusted for political realities. No techniques exist for laying out a "normal" schedule against which contractor and PO schedules can be assessed. Yet, FSD cost estimates cannot be evaluated unless the relationship between the proposed schedule and a "normal" schedule is understood.

Every Product Division expressed interest in the schedule and cost impacts of schedule changes. Mr Heydinger (SD) suggested collecting data on schedule growth. He also wanted to find ways of schedule shortening (an SDI requirement). Mr Townsend (SD) wanted to know the cost consequences of schedule change. Mr Malik (AD) wanted an initial schedule estimate, sensitive to technology. Mr Scherrer (ASD) wanted schedule estimating techniques. Mr Kielpinski (ESD) was concerned with estimating the cost of management reserve as a function of schedule compression. Mr Ritchey (ASD) noted that schedule ddata is being collected on airframe production. Development data will be collected next. Mr Hansen (BMO) mentioned the imprtance of schedule normalization.

The first priority is to collect consistent schedule data. This is being done at each of the Product Divisions. However, a big technical problem remains. That is the development of schedule normalization techniques. Without these, trying to build schedule estimating relationships will be equivalent to trying to make CERs on they-year cost data. Schedule must be normalized for three effects: (1) Crash Program (compressed schedule), (2) Accelerated Technology Development (technology compression), and (3) Budget Cuts (schedule expansion).

Once developed, these normalization techniques ought to be applied to a schedule data base, thus normalizing the data. Derivation of s hedule estimating relationships can then be attempted.

RELATED AREAS: Technology compression techniques (research area VIII) call for the development of techniques to adjust normal schedules/cost when a technology enhancement is required to meet production earlier than the normal evoluationary rate of technology gorwth would permit. These may be useful in schedule normalization. Imbedded schedule inefficiencies, other research area o2, may have some overlap, although this looks for ways to reduce schedules rather than normalize them. ECO cost estimates and cost/schedule technical risk costs (#7 in 04) should be related to normal schedule or lack thereof. Cost penalty for concurrency, mentioned in (S4), also should be considered here.

DOABILITY: Uncertain. Schedule normalization is a difficult area which needs some basic research. Normal CER development procedures can be used to make schedule estimating relationships once the schedule data is normalized.

PRIORITY:

EXTREME	HIGH	MEDIUM	LOW
X			

RECOMMENDATION: Initiate a modest effort into identifying ways to normalize schedule data. Attempt to collect schedule data including information for normalization.

RESEARCH STEPS:

1. Define candidate normalization procedures.
2. Design data collection instrument incorporating (1) above.
3. See if any existing data bases contain the data.
4. If yes, attempt to build schedule estimating relationships for the data.

Sections 4 - 7

Interactions among the New Research Areas are presented in Section 4. Flow charts show how tools from the Research Areas will be used in making the independent cost estimates and special cost studies required by the Air Force.

Technology Areas are presented in Section 5. These include five specific technologies plus a call for technology roadmaps. The full discussion of technology roadmaps is included because of their importance.

Other Research Areas are presented in Section 6, followed by Survey Areas in Section 7. Evaluation of Estimates made by PRICE and correcting for Biased Cost Drivers are examples.

TECHNOLOGY AREA T6

TECHNOLOGY ROADMAPS

DESCRIPTION: Develop technology and system-oriented roadmaps.

SIGNIFICANCE: Realistic technology projections are extremely important. Failure to realize optimistic projections by contractors results in loss of performance and increased cost.

PRODUCT DIVISION INTEREST (APPLICABILITY):

AD	ASD	BMO	ESD	SD
X	X	X	X	X

DISCUSSION: The detailed work on system requirements and technolgoy roadmpas begun at SD is extremely important. Similiar efforts are required at all Product Divisions. Ms Coakley (ESD) recognized the requirement but said that no effort has been made by ACC. Technology forecasting is done by the two-letter divisions. No combined list has been made.

Mr Scherrer (ASD) felt better technology forecasts from engineering are requried so that good time estimates can be associated with the new technologies. These technology time lines should be presented in terms of the performance level acheived over time. Program offices will then be less likely to prematurely depend on performance levels which cannot be achieved in time. These timelines will also set priorities to the cost community in developing appropriate cost estimating techniques.

It is the author's opinion that ACCs at the Product Divisions should work with technologists to translate forecasts into a usable roadmap for the Product Divisions. ACC has the proper overview, while technologists tend to provide too much detail in a non-usable form.

RELATED AREAS: The output of these roadmaps will be used to establish SOA measures (research area I) and changes to these for new technology (research area VI). They will also be used to identify the need for schedule (technical) compression (research area VIII).

DOABILITY: Space Division (under AFSC sponsorship) has completed a microelectronics roadmap and a space systems roadmap. These need to be married together to see if needs and timing can be met by the new technologies. Other Product Divisions need to develop similiar roadmaps.

PRIORITY:

EXTREME	HIGH	MEDIUM	LOW
X			

RECOMMENDATION: Marry two SD roadmaps together and publish as an example to other Product Divisions.

RESEARCH AREAS:

1. Marry two roadmaps.

2. Write a tutorial on how to prepare these roadmaps and distribute to other Product Divisions.

3. Describe system, subsystem, and component SOA for selected applications to determine use in research areas I, VI, and VIII.

5

OTHER RESEARCH AREAS

Comments from the interviews were reviewed and cross-referenced into topic.areas. These topic areas were then critically reviewed, looking for significant research problems which had an expressed interest from several Product Divisions. Results of this review are contained in this section, organized around the following topies:

01. Software Size Estimating

02. Historical Schedule Inefficiencies

03. Estimate Quality

04. Non-Primary MIssion Equipment Costs

05. Host Evhicle/Subsystem Integration Costs

06. Commonality Problems

07. Software Cost Estimating

08. Evaluation of Estimates made by PRICE

In some instances, the topic already has had significant work. A critical survey and distribution of the results seemed more appropriate than a research task. These topics are discussed in section 6.

RESEARCH AREA 08

EVALUATION OF ESTIMATES MADE BY PRICE

DESCRIPTION: How good is PRICE for estimating the costs of future advanced systems?

SIGNIFICANCE: PRICE computer programs have been used as a primary estimating technique by a number of the Product Divisions. The accuracy of PRICE cannot be theoretically calculated due to the balck box nature of the model. Thus, the quality of many Air Force cost estimates using PRICE is suspect.

PRODUCT DIVISION INTEREST (APPLICABILITY):

AD	ASD	BMO	ESD	SD
X	X		X	X

DISCUSSION: PRICE cost estimating models (both hardware and software) have had increasing use by the Air Force. The models are fairly easy to use and they produce answers quickly and efficiently. However, the estimating techniques, scaling rules, etc. which consistitute the model are not visible to the user. All that is known is that the model can be calibrated to the user's data and that accurate estimaes will be made if the right inputs are given. Since some of these inputs are judgmental (complexity factors), correct use of the model can boil down to having the right judgment.

These complexity factors are so important that users have begun studying their nature. PRICE is run backwards, entering the cost as an input variable, and calculating the implied complexity factors. These factors are called ECIRP factors (PRICE spelled backwards). At AD, PRICE is used extensively and the calculation of ECIRP factors is part of any data collection effort (Mr Soler).

Various analysts are becoming concerned and would like an objective way to evaluate PRICE. Mr Malik (AD) wants to know how good pRICE is in forecasting the cost of technically advanced systems. Mr Back (ASD), Mr Foster (AD), and Mr Scherrer (ASD) all feel that alternatives are needed, or at least that the situations for valid PRICE use need to be identified. Capt Dean (ESD) wants to know how PRICE estimates software-hardware integration costs.

Since PRICE is calibrated, to date is seems likely that it can produce good estimates within the range of the data (interpolation). But what information does PRICE use to extrapolate? What are the scaling rules?

Mr Koscielski (SD) reported that people are studying ECIRP factors and building relationships which estimate ECIRP values based on system physical and performance characteristics. Thus, physical and performance characteristics of a new system can be used to estimate ECIRP values. These ECIRP values are then input to PRICE and the cost estimate obtained.

This scheme could be evaluated with techniques developed in new research area II.

RELATED AREAS:

Techniques in research area II can be used to test PRICE extrapolation.

DOABILITY: Not difficult or costly if ECIRP data base exists.

PRIORITY:

EXTREME	HIGH	MEDIUM	LOW
	X		

RECOMMENDATION: Conduct an evaluation of PRICE extrapolation capability using techniques for research area II.

RESEARCH STEPS:

1. Obtain ECRIP data base.

2. Define area II evaluation technique.

3. Perform evaluation.

7

SURVEY AREAS

Comments from the interviews were reviewed and cross-referenced into topic areas. Each topic area was then analyzed to find problems of common interest. In several cases these problems of common interest were in areas where significant prior research has beendone. These topies are discussed in the following pages with, in some cases, a recommendation for a critical survey and distribution of the resutls to the Product Divisions.

The following topics are presented:

S1. Correcting for Biased Cost Drivers

S2. Impbedded cost Estimating Practices

S3. Competition Impacts

S4. Other Contracting Method Problems

S5. Production Rate Effects

S6. Contractor Integration Cost Estimation

SURVEY AREA S1

CORRECTING FOR BIASED COST DRIVERS

DESCRIPTION: Conduct a review of AFSC work done in this area. Critique, document, and distribute findings.

SIGNIFICANCE: Cost estimates will be low when they are made using models with cost drivers that are underestimated. Significance depends on the amount of bias in each cost driver estimate. Zero to 70 percent is very likely.

PRODUCT DIVISION INTEREST (APPLICABILITY):

AD	ASD	BMO	ESD	SD
X	X	X	X	X

DISCUSSION: There was great consensus on the importance of making estimates with cost drivers (independent variables) which are available early (Mr Ritchey-ASD and Mr Townsend-SD). A corollary is that the cost driver informationa must be accurate early on. However, many cost drivers are historically estimated low early in the system life cycle. Examples are number of test flights (Mr Thompson0ESD), spacecraft wegith (Mr Heydinger-SD), and number of circuit boards (Mr Soler-AD). Another example is software size (research area 01). These biased cost drivers can be found by tracking their estimated value between DSARC I and DSARC II (Mr Soler).

Having identified the biased cost drivers, how does one correct for them? Three techniques are possible:

1. Develop unbiased estimates of the cost drivers. This is being suggested for software size in research are 01.

2. Develop correction factors for the cost driver. SD (Mr Heydinger) has correction factors (percentage increase) for satellite weight at key milestones. These are applied unless the PO can make a strong case that the historical cost driver underestimate has already been corrected for.

3. Develop an alternative unbiased cost driver which is also available early on. Size of specifications is an example for software. This is suggested as other research area 07.

RELATED AREAS: Sofware sizing estimate, other research area 01; and software cost model baesd on specifications, other research area 07; are examples of 1 and 3 above.

DOABILITY: Should be easy to collect, critique, and disseminate this information.

PRIORITY:

EXTREME	HIGH	MEDIUM	LOW
	X		

RECOMMENDATION: A modest project to collect, critique, and distribute information about this topic should be accomplished this next fiscal **year.**

RESEARCH STEPS:

1. Identify other biased cost drivers and correction techniques.
2. Review and critique supportive material.
3. Prepare report.
4. Disseminate to Product Divisions.

8

RECOMMENDATIONS

OVERVIEW

This study approached the question of new research areas for cost analysis from two directions.

1. First, the focus was on identifying areas where the cost community tools are not adequate. A framework was developed to examine the quality of cost analysis with respect to both technology and systems life-cycle phase. Nine new research areas were identified and examined in section 3. Priorities were assigned and are summarized in table 8.1. Although this assessment was primarily accomplished by the author, the new research areas were discussed with some interviewees, which resulted in formulating new research areas IV and IX and fine-tuning the other areas.

2. Second, areas of major concern to cost analysts of the various Product Divisions were identified during the interviews. Notes from the interviews were examined for consensus. Ideas were grouped into technology areas (section 5) and additional research areas. These additional research areas were then divided into other research areas (section 6) and survey areas (sction 7). Survey areas were those with significant prior research where a critical survey should not only disseminate the ideas to the various Product Divisions, but also provide proper review for identifying the next research step, if any. consensus of interest, research (survey) potential, and doability. This resulted in a priority raking shown in table 8.1.

The interview process also surfaced a great deal of interest in topics that were not suitable for cost research and were therefore excluded. The following are examples:

<u>Data collection</u> was a concern of ten interviewees. Topics varied but the need for more data was, as always, a principal concern. Furthermore, it was asserted that data should be maintained, not just collected.

<u>Data collection standardization</u> was a concern for nine interviewees. Data collection alone is not sufficient. Standard WBSs across systems are required. Cost models and reports should use the same standardized format. Then analyses and comparisons can be accomplished.

Source-selection support was another concern. The cost analyst can provide invaluable support in normalization of bids and identifying bid rates with significant bottom line cost impacts. The cost analyst often sees the forest while negotiators are examining the trees. Another service that the cost analyst can provide is to estimate the impacts of award selections upon burden rates for other contractor in-house DOD work.

Also excluded from this review were (1) O&S costs, (2) institutional and procedural changes, (3) automation to increase estimating efficiency, (4) technical recruiting, and (5) Black world applications. These were excluded from the outset and were therefore not discussed in the intereviews.

SPECIFIC RECOMMENDATIONS

The priority rankings in table 8.1 give an order to the pursuit of these research areas. The extreme priority calls for study immediately. A high priority recommends studies during the fiscal year. Medium are those areas which should be explored, funding permitting. Low indicates an area that does not have enough common interest or application to be pursued at the AFSC level. A low rating does not assert that the idea was not worth pursuing, but rather that the investigation should be pursued by a more focused user group.

Rankings within each of the priority classes were then made and reasons for the ranking given. These are presented in the full text, available in early October.

Table 8.1

SUMMARY OF RESEARCH AREA PRIORITIES

	Extreme	High	Medium	Low
Research Areas				
I. Quantify State of the Art	X			
II. Extrapolation Estimators for Evolutionary Advance		X		
III. Technology Breakthrough Evaluation Prior to DSARC II		X		
IV. DSARC I Cost Estimating Methods		X		
V. Technology Impact on Acquisition Costs		X		
VI. Technology Impact on SOA System Characteristics		X		
VII. Normal FSD Schedule/Cost Estimate	X			
VIII. FSD Cost Consequences of Technology(Schedule) Compression			X	
IX. Methods to Estimate Advanced Development Cost				X
Technology Areas				
T1. VHSIC		X		
T2. CAD	X			
T3. CAM	X			
T4. GaAs				X
T5. Composite Materials	X			
T6. Technology Road Maps	X			

Table 8.1 (Continued)

	Extreme	High	Medium	Low
Other Research Areas				
O1. Software Size Estimating	X			
O2. Historical Schedule Inefficiencies			X	
O3. Estimate Quality	X			
O4. SEPM Model		X		
O5. Platform Integration Costs	X			
O6. Commonality Problems				X
O7. Software Costs as Function of Software Functional Specification		X		
O8. Evaluate PRICE/ECIRP for Technically Advanced Systems		X		
Survey Areas				
S1. Correcting for Biased Cost Drivers		X		
S2. Imbedded Cost Estimating Practices				X
S3. Competition Impacts		X		
S4. Multiyear Procurement and Warranties		X		
S5. Production Rate Effects	X			
S6. Contractor Integration and Checkout Cost at All Levels			X	

SUMMARY

The Road Map is an important document in helping to prioritize funding of CMIP projects. It will allow AFSC to better spend its research funds and project where research is needed to improve it's cost estimating "tool box". The bottom line is to ensure that AFSC continues to deliver quality cost estimates for acquiring new weapon systems. As technology changes so must the methods of estimating the systems/technology.

If the Road Map is to continue to be of use it must be regularly updated. Once the Road Map is used to prioritize a given year's projects and budgets, the results of ongoing projects, changes in technology and the way systems are acquired must be reevaluated to reflect the needs for the following years set of projects. The Road Map is a living document of the cost estimating needs of the Air Force.

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